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Azami

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(54) **POSITION SPECIFYING SERVER, POSITION SPECIFYING METHOD, AND RECORDING MEDIUM RECORDING POSITION SPECIFYING PROGRAM**

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(51) **Int. Cl.**
H04W 4/04 (2009.01)
H04W 4/02 (2009.01)

(52) **U.S. Cl.**
CPC .. ***H04W 4/04*** (2013.01); *H04W 4/02* (2013.01)

(58) **Field of Classification Search**
CPC H04W 4/04
USPC 342/450, 357.2, 357.22, 357.23, 342/357.24, 357.25, 357.28, 357.34, 342/357.39, 357.44, 357.48, 357.47, 386; 455/456.1–457
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

8,385,943	B1 *	2/2013	Han et al.	455/456.1
2006/0087425	A1 *	4/2006	Haeberlen	G01S 5/0252 340/539.13
2007/0133487	A1 *	6/2007	Wang et al.	370/338
2009/0286548	A1 *	11/2009	Coronel et al.	455/456.1
2010/0026513	A1 *	2/2010	Pandey	G06K 7/0008 340/8.1
2010/0317366	A1 *	12/2010	Shen	G01S 19/48 455/456.1
2012/0295637	A1 *	11/2012	Hannuksela et al.	455/456.1
2013/0260771	A1 *	10/2013	Wirola	H04W 16/18 455/446
2014/0011518	A1 *	1/2014	Valaee et al.	455/456.1

FOREIGN PATENT DOCUMENTS

JP B2-4840395 12/2011

* cited by examiner

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(57) **ABSTRACT**

A position specifying server includes a storage unit, a communication unit, an estimation unit, and a specifying unit. The storage unit stores GMMs corresponding to base stations of radio waves receivable by a terminal device on each floor. The communication unit receives measured values of the radio wave strengths of the radio waves which the terminal device receives from the base stations. The estimation unit estimates a position of the terminal device for each floor based on the received measured values of the radio wave strengths and the GMMs. The specifying unit calculates the estimated values of the radio wave strengths at the estimated position of the terminal device on each floor based on the GMMs and specifies the floor on which the terminal device is present based on the calculated estimated values of the radio wave strengths and the measured values of the radio wave strengths.

17 Claims, 13 Drawing Sheets

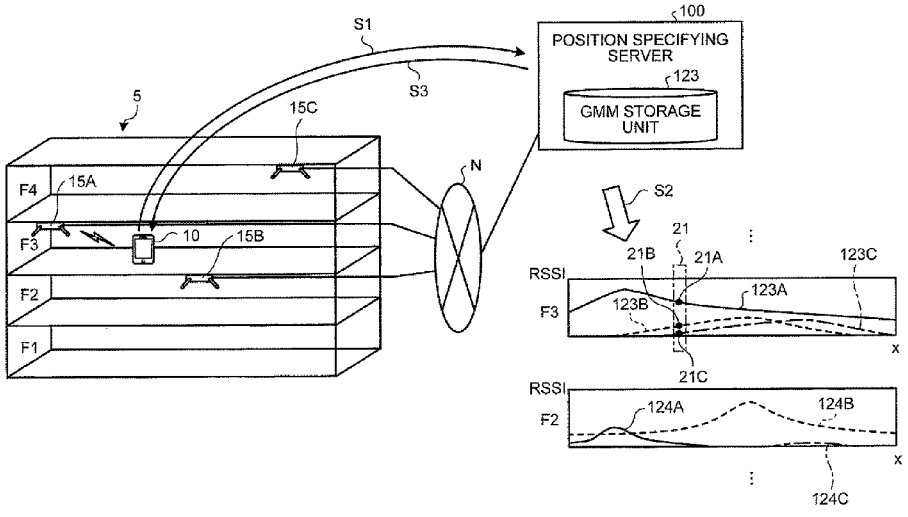


FIG.1

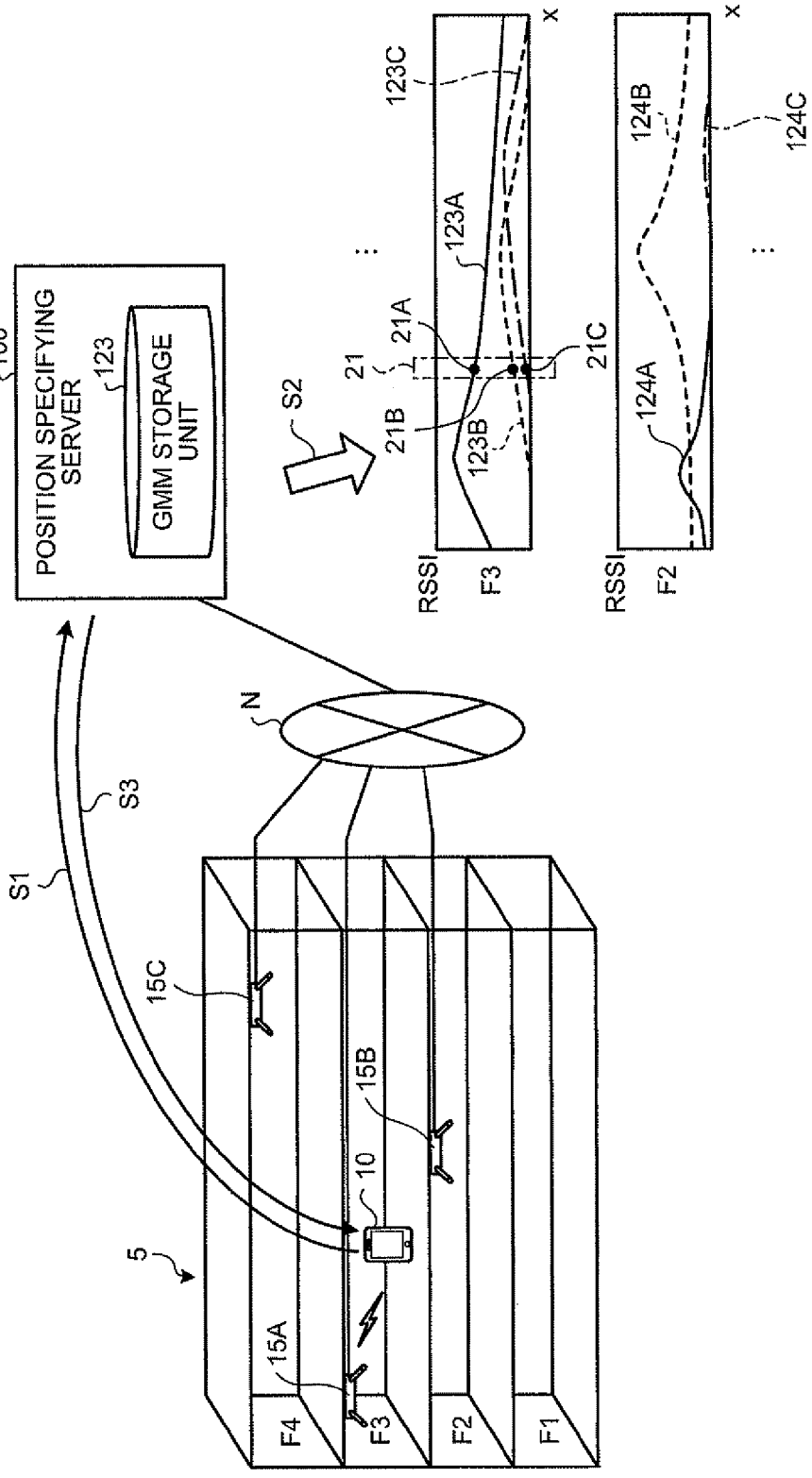

100
POSITION SPECIFYING SERVER
123
GMM STORAGE UNIT
S1
S2
S3
N
5
10
15A
15B
15C
F1
F2
F3
F4
21
21A
21B
21C
123A
123B
123C
124A
124B
124C
RSSI
x

FIG.2

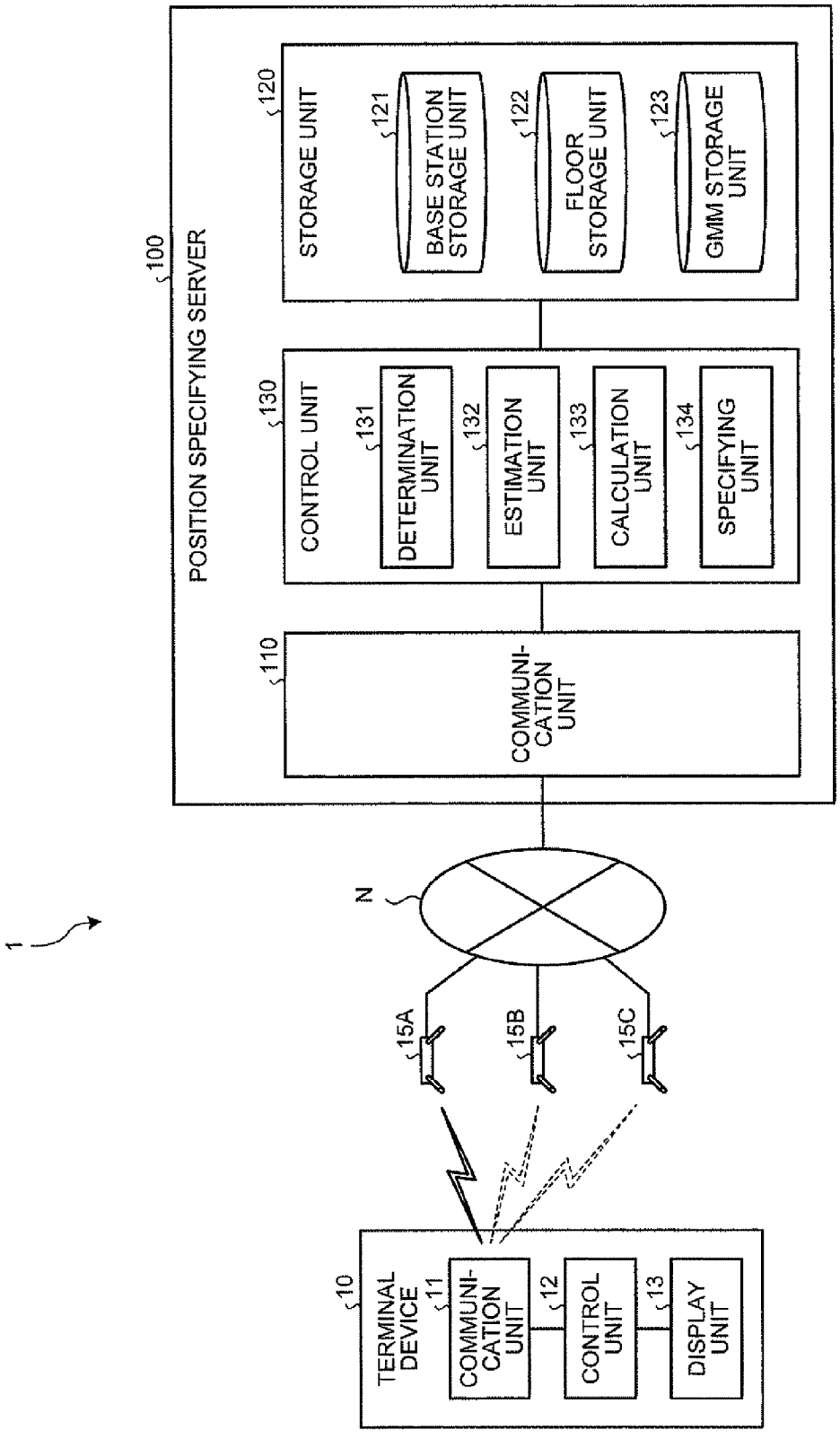

1
100
POSITION SPECIFYING SERVER
110
COMMUNI-CATION UNIT
120
STORAGE UNIT
121
BASE STATION STORAGE UNIT
122
FLOOR STORAGE UNIT
123
GMM STORAGE UNIT
130
CONTROL UNIT
131
DETERMINATION UNIT
132
ESTIMATION UNIT
133
CALCULATION UNIT
134
SPECIFYING UNIT
N
15A
15B
15C
10
TERMINAL DEVICE
11
COMMUNI-CATION UNIT
12
CONTROL UNIT
13
DISPLAY UNIT

FIG.3

121

BSSID	REPRESEN-TATIVE LATITUDE	REPRESEN-TATIVE LONGITUDE	MaxRSSI	GMMFlag	RECEIVABLE FLOOR ID	...
aaa123bbb456	35.xxxxxxx	136.xxxxxxx	-75.0	1	F2, F3	...
789ccc012ddd	35.yyyyyyy	136.yyyyyyy	-82.0	1	F2, F3, F4	...
ee34ff56gg78	35.zzzzzzz	136.zzzzzzz	-95.0	0	F1	...
...	...	...	...	...	...	...

FIG.4

122

FLOOR ID	FILE NAME OF FLOOR DRAWING	WIDTH OF FLOOR DRAWING	HEIGHT OF FLOOR DRAWING	LONGITUDE AND LATITUDE OF FLOOR								FLOOR NUMBER	...
				UPPER LEFT		LOWER LEFT		UPPER RIGHT					
				LATITUDE	LONGITUDE	LATITUDE	LONGITUDE	LATITUDE	LONGITUDE				
F1	F1.png	1824	1290	35.xx	139.xx	35.yy	139.yy	35.zz	139.zz			1	...
F2	F2.png	1824	1290	35.xx	139.xx	35.yy	139.yy	35.zz	139.zz			2	...
F3	F3.png	1824	1290	35.xx	139.xx	35.yy	139.yy	35.zz	139.zz			3	...
F4	F4.png	1824	1290	35.xx	139.xx	35.yy	139.yy	35.zz	139.zz			4	...
...	...	...	...	...	...	...	...	...	...			...	...

FIG.5

123

FLOOR ID	NUMBER OF BSSIDs	BSSID	K	π	μ_x	μ_y	Σ_{11}	Σ_{12}	Σ_{22}	...
F1	11	aaa123bbb456	8	0.1	-78.3	-79.8	1	2	1	...
		789ccc012ddd	8	0.1	-85.6	-86.7	2	1	1	...
		ee34ff56gg78	8	0.2	-98.1	-97.6	1	1	1	...
		...	...	...	...	...	...	...	...	...
F2	22	asd076jyvu89	8	0.05	-55.3	-54.2	1	1	2	...
		qwe678hjk6yh	8	0.05	-61.5	-61.1	1	2	2	...
		zdt7ui9k3n9ha	8	0.05	-68.4	-70.2	2	2	1	...
		...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	...

FIG.6

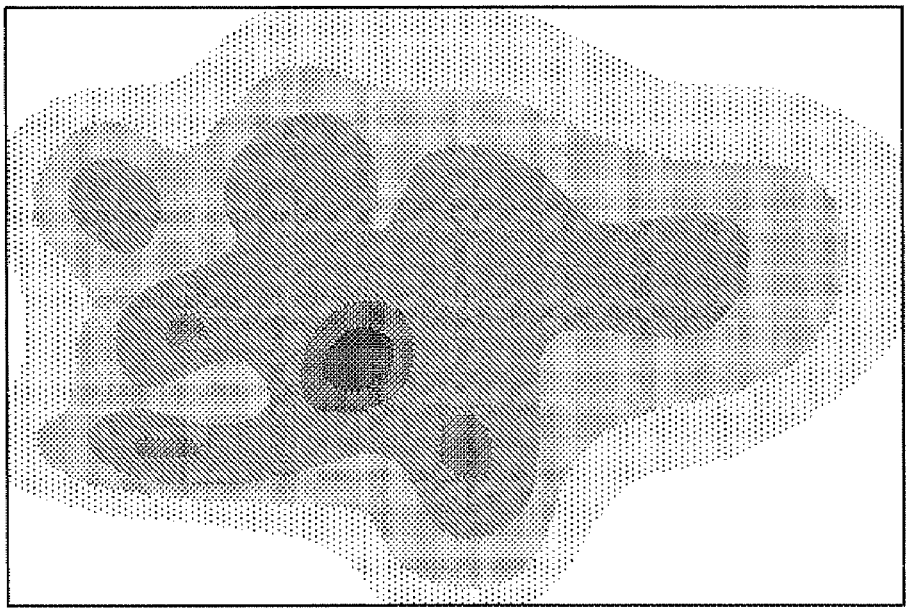


FIG.7

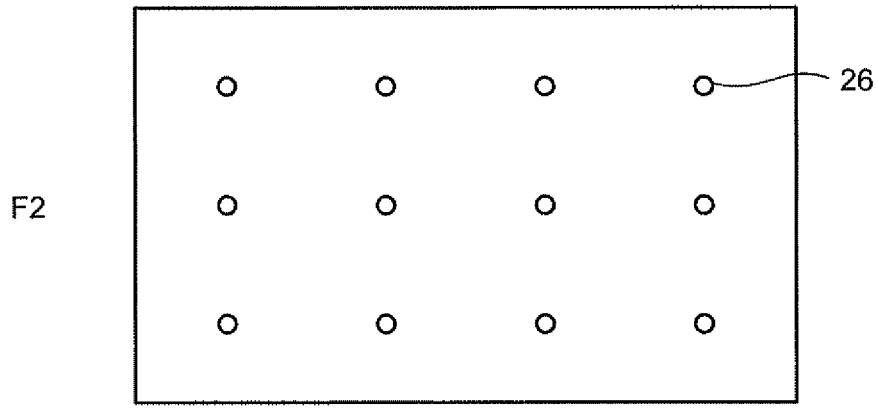


FIG.8

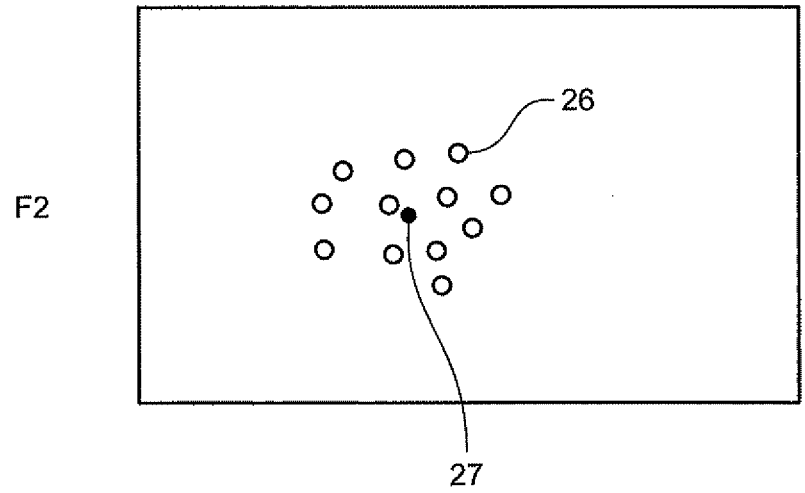


FIG.9

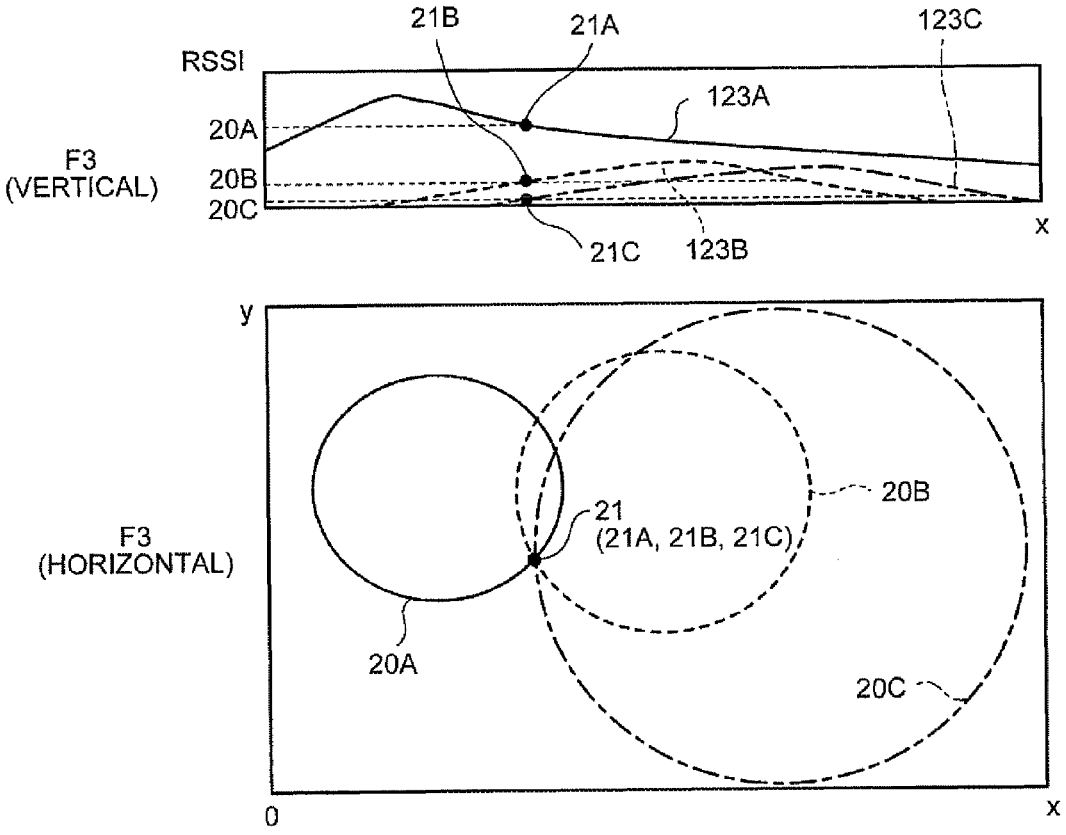

21B
21A
123C
RSSI
123A
20A
F3
(VERTICAL)
20B
20C
x
21C
123B
y
F3
(HORIZONTAL)
20B
21
(21A, 21B, 21C)
20A
20C
0
x

FIG.10

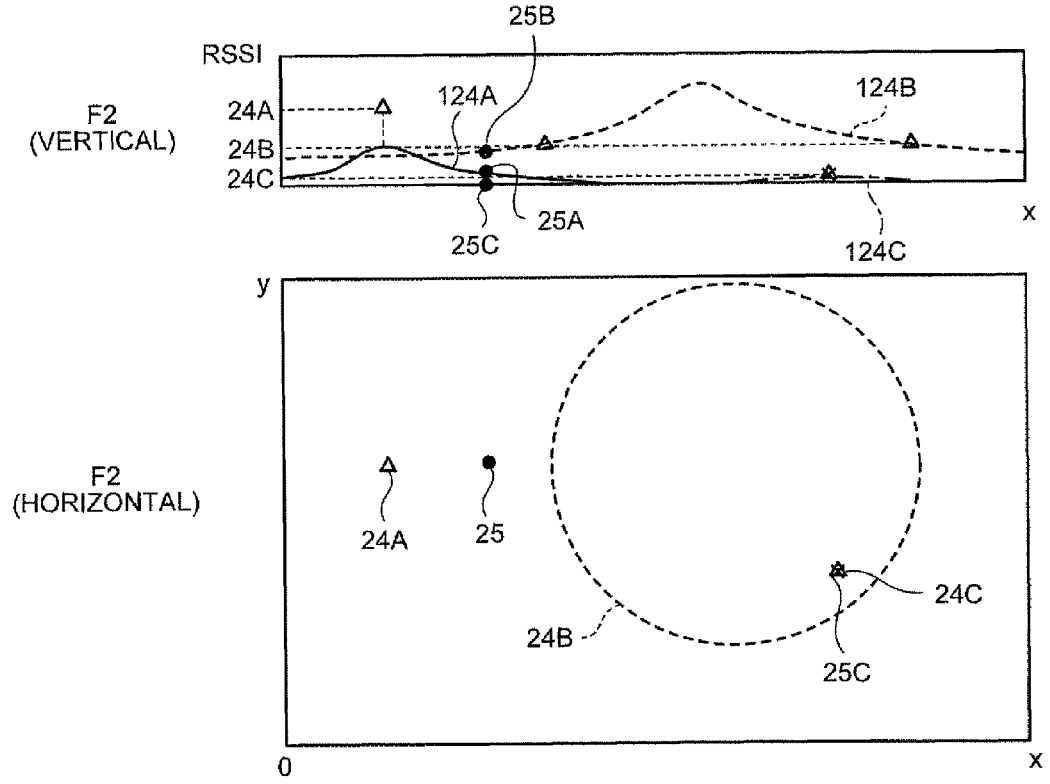

F2
(VERTICAL)
RSSI
24A
24B
24C
25B
124A
124B
25C
25A
124C
x
F2
(HORIZONTAL)
y
24A
25
24C
24B
25C
0
x

FIG.11

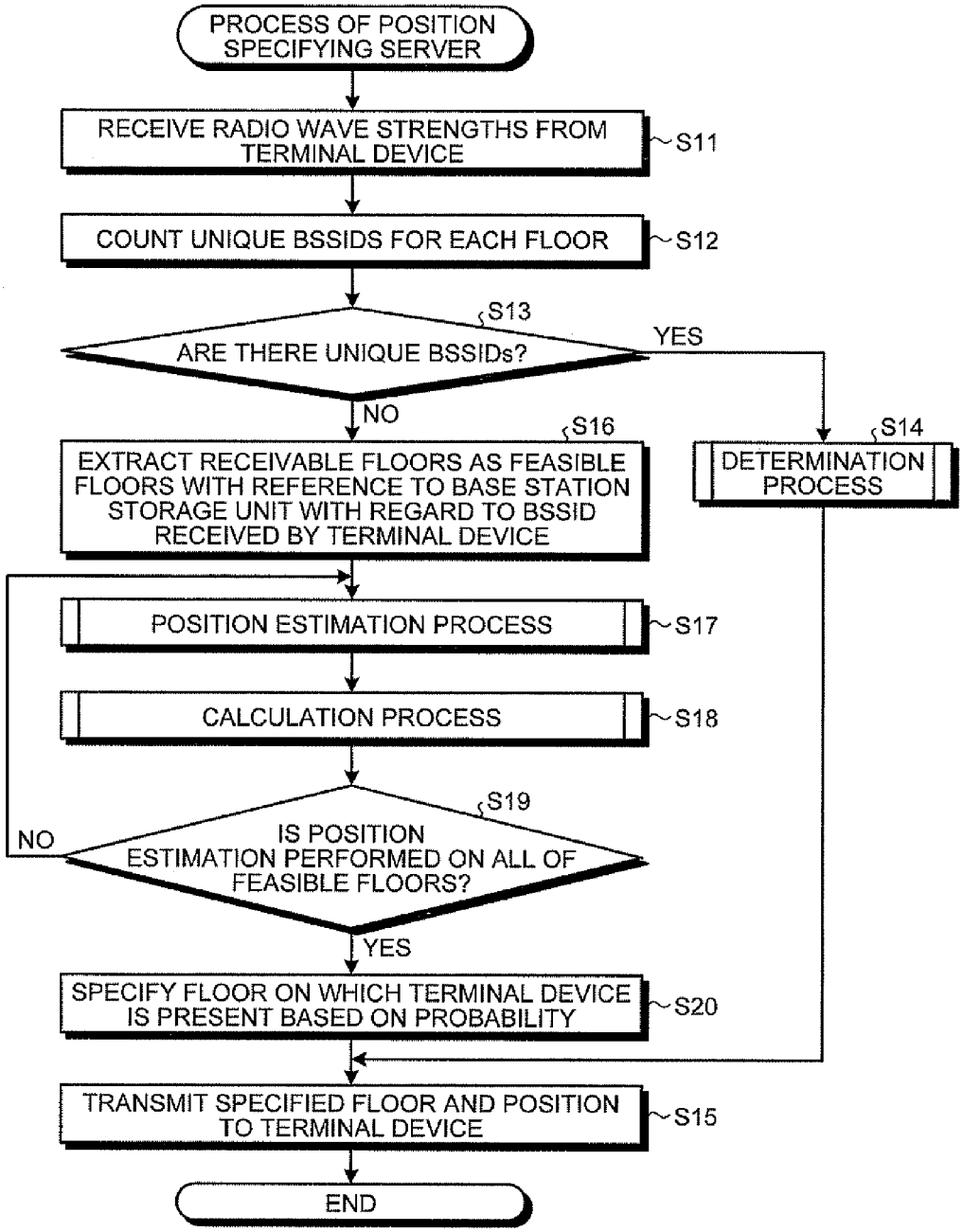

PROCESS OF POSITION SPECIFYING SERVER
RECEIVE RADIO WAVE STRENGTHS FROM TERMINAL DEVICE
S11
COUNT UNIQUE BSSIDS FOR EACH FLOOR
S12
S13
ARE THERE UNIQUE BSSIDs?
YES
NO
S16
EXTRACT RECEIVABLE FLOORS AS FEASIBLE FLOORS WITH REFERENCE TO BASE STATION STORAGE UNIT WITH REGARD TO BSSID RECEIVED BY TERMINAL DEVICE
S14
DETERMINATION PROCESS
POSITION ESTIMATION PROCESS
S17
CALCULATION PROCESS
S18
S19
NO
IS POSITION ESTIMATION PERFORMED ON ALL OF FEASIBLE FLOORS?
YES
SPECIFY FLOOR ON WHICH TERMINAL DEVICE IS PRESENT BASED ON PROBABILITY
S20
TRANSMIT SPECIFIED FLOOR AND POSITION TO TERMINAL DEVICE
S15
END

FIG.12

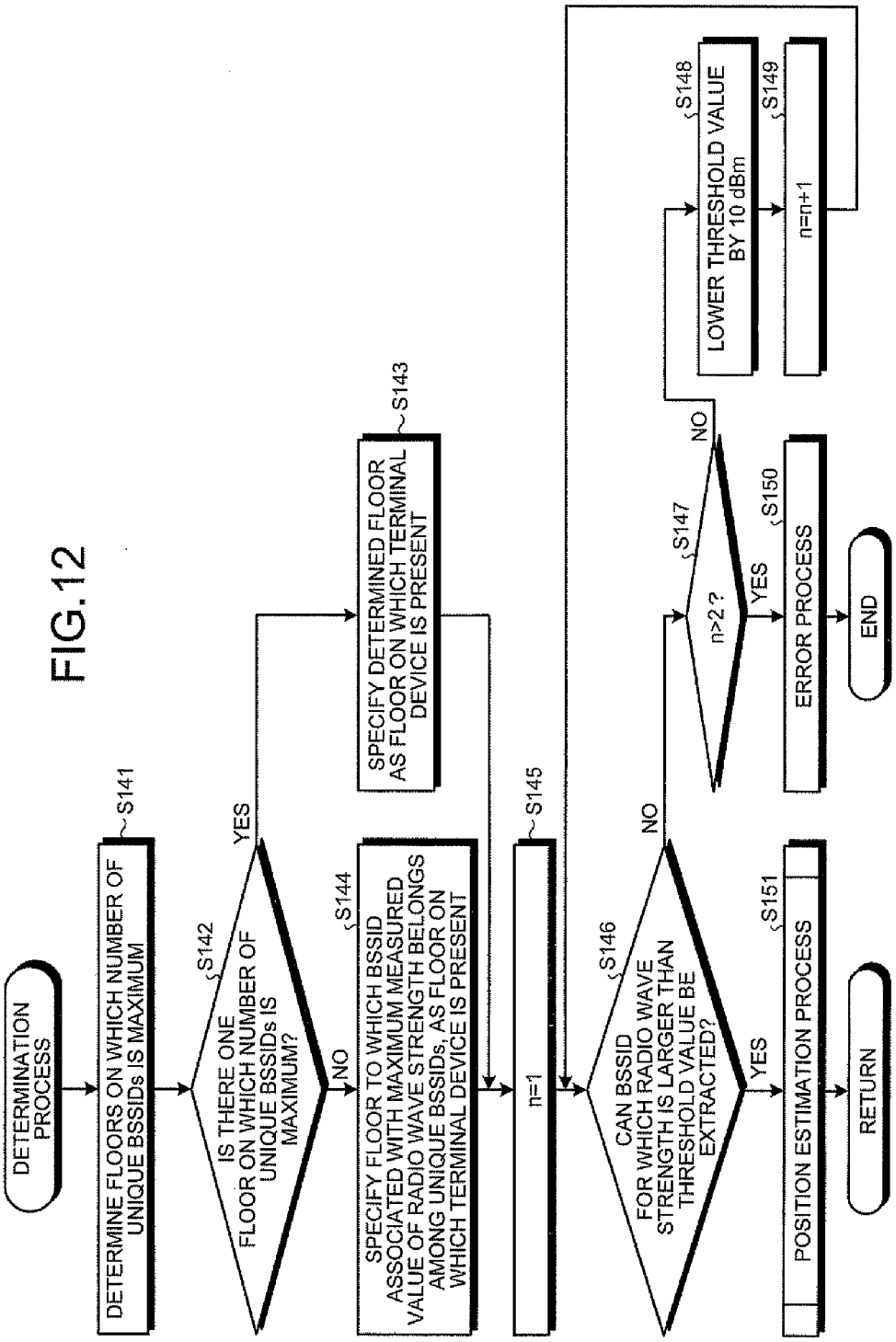

DETERMINATION PROCESS
DETERMINE FLOORS ON WHICH NUMBER OF UNIQUE BSSIDs IS MAXIMUM
S141
IS THERE ONE FLOOR ON WHICH NUMBER OF UNIQUE BSSIDs IS MAXIMUM?
S142
YES
NO
SPECIFY DETERMINED FLOOR AS FLOOR ON WHICH TERMINAL DEVICE IS PRESENT
S143
SPECIFY FLOOR TO WHICH BSSID ASSOCIATED WITH MAXIMUM MEASURED VALUE OF RADIO WAVE STRENGTH BELONGS AMONG UNIQUE BSSIDs, AS FLOOR ON WHICH TERMINAL DEVICE IS PRESENT
S144
n=1
S145
CAN BSSID FOR WHICH RADIO WAVE STRENGTH IS LARGER THAN THRESHOLD VALUE BE EXTRACTED?
S146
NO
YES
n>2 ?
S147
NO
YES
LOWER THRESHOLD VALUE BY 10 dBm
S148
n=n+1
S149
ERROR PROCESS
S150
END
POSITION ESTIMATION PROCESS
S151
RETURN

FIG.13

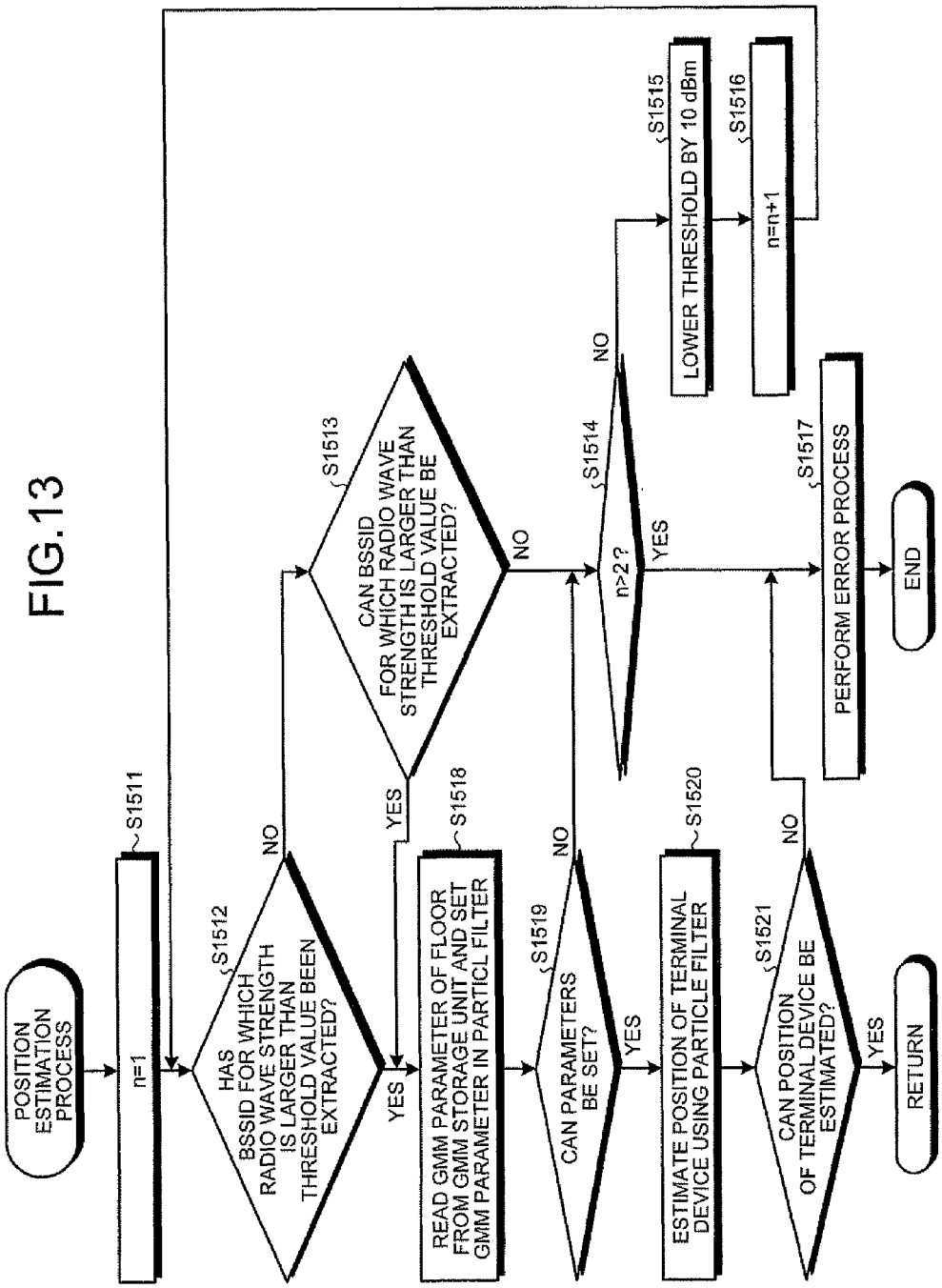

POSITION ESTIMATION PROCESS
n=1
S1511
HAS BSSID FOR WHICH RADIO WAVE STRENGTH IS LARGER THAN THRESHOLD VALUE BEEN EXTRACTED?
S1512
NO
YES
CAN BSSID FOR WHICH RADIO WAVE STRENGTH IS LARGER THAN THRESHOLD VALUE BE EXTRACTED?
S1513
NO
YES
n>2?
S1514
NO
YES
LOWER THRESHOLD BY 10 dBm
S1515
n=n+1
S1516
PERFORM ERROR PROCESS
S1517
END
READ GMM PARAMETER OF FLOOR FROM GMM STORAGE UNIT AND SET GMM PARAMETER IN PARTICL FILTER
S1518
CAN PARAMETERS BE SET?
S1519
NO
YES
ESTIMATE POSITION OF TERMINAL DEVICE USING PARTICLE FILTER
S1520
CAN POSITION OF TERMINAL DEVICE BE ESTIMATED?
S1521
NO
YES
RETURN

FIG.14

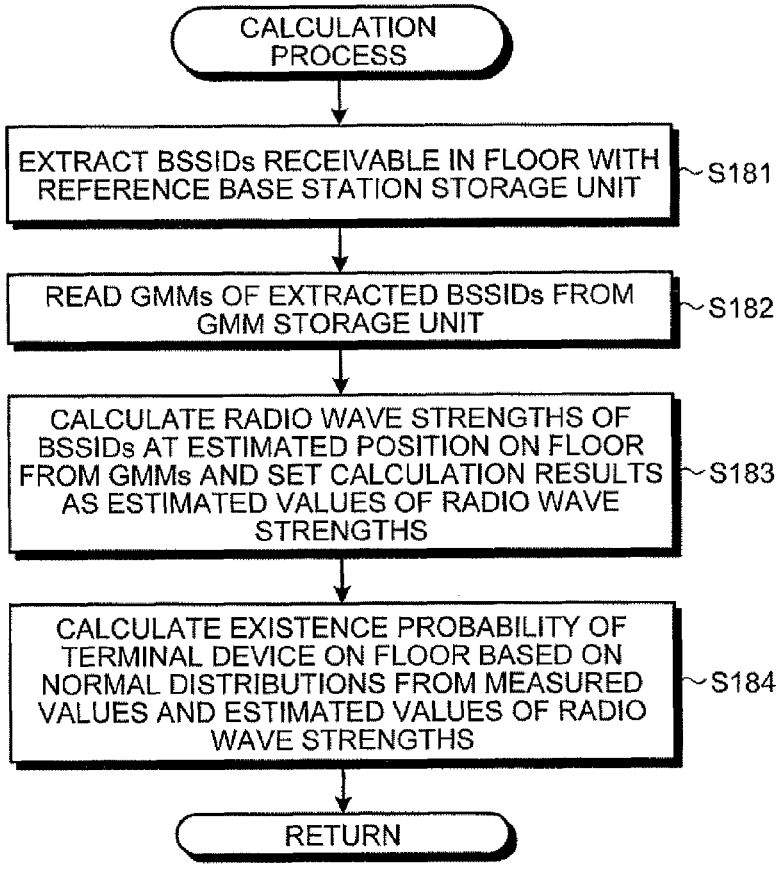
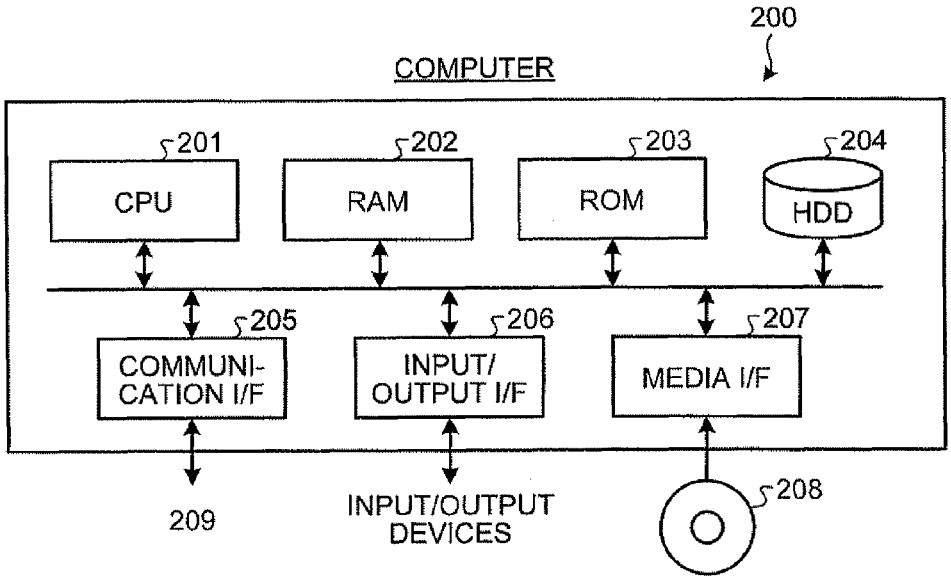

CALCULATION PROCESS
EXTRACT BSSIDs RECEIVABLE IN FLOOR WITH REFERENCE BASE STATION STORAGE UNIT
S181
READ GMMs OF EXTRACTED BSSIDs FROM GMM STORAGE UNIT
S182
CALCULATE RADIO WAVE STRENGTHS OF BSSIDs AT ESTIMATED POSITION ON FLOOR FROM GMMs AND SET CALCULATION RESULTS AS ESTIMATED VALUES OF RADIO WAVE STRENGTHS
S183
CALCULATE EXISTENCE PROBABILITY OF TERMINAL DEVICE ON FLOOR BASED ON NORMAL DISTRIBUTIONS FROM MEASURED VALUES AND ESTIMATED VALUES OF RADIO WAVE STRENGTHS
S184
RETURN

FIG.15


200
COMPUTER
201
CPU
202
RAM
203
ROM
204
HDD
205
COMMUNI-CATION I/F
206
INPUT/ OUTPUT I/F
207
MEDIA I/F
209
INPUT/OUTPUT DEVICES
208

POSITION SPECIFYING SERVER, POSITION SPECIFYING METHOD, AND RECORDING MEDIUM RECORDING POSITION SPECIFYING PROGRAM

CROSS-REFERENCE TO RELATED APPLICATIONS

The present application claims priority to and incorporates by reference the entire contents of Japanese Patent Application No. 2013-176130 filed in Japan on Aug. 27, 2013.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a position specifying server, a position specifying method, and a recording medium recording a position specifying program.

2. Description of the Related Art

In the related art, using radio waves of base stations of a wireless local area network (LAN) has been suggested for a person or the like carrying a terminal device to perform positioning in an indoor place or the like where radio waves of the global positioning system (GPS) do not reach. The positioning using a wireless LAN can be realized, for example, by comparing radio wave strengths from respective base stations with measured values of the radio wave strengths in a terminal device that uses a database storing the radio wave strengths from the respective base stations measured in advance at each place within a building. To specify a floor of a building, the device having the database stores the radio wave strengths and identification information of the base stations measured in advance in each floor in a storage unit and retrieves the radio wave strengths and the identification information of the base stations received by a terminal device performing the positioning from the storage unit. Based on the retrieval result, the device having the database selects a floor which is matched with a number of pieces of identification information of the same base station (for example, Japanese Patent No. 4840395).

In the measured value data of the radio wave strength measured in each place in a building, however, it is necessary to finely set meshes of the measurement points to improve accuracy of the positioning. Therefore, the database may be enlarged, thereby increasing a load. To determine the floor in the building using the number of floors matched with the same base station, data of all of the base stations in the building is necessary. Therefore, the database may be also enlarged.

SUMMARY OF THE INVENTION

It is an object of the present invention to at least partially solve the problems in the conventional technology.

According to one aspect of an embodiment, a position specifying server includes: a storage unit that stores GMMs corresponding to base stations of radio waves receivable by a terminal device and indicating radio wave strengths on each floor; a communication unit that receives measured values of the radio wave strengths of the radio waves which the terminal device receives from the base stations; an estimation unit that estimates a position of the terminal device for each floor based on the received measured values of the radio wave strengths and the GMMs; and a specifying unit that calculates the estimated values of the radio wave strengths at the estimated position of the terminal device on each floor based on the GMMs corresponding to the base stations and specifies the floor on which the terminal device is present based on the calculated estimated values of the radio wave strengths and the measured values of the radio wave strengths.

The above and other objects, features, advantages and technical and industrial significance of this invention will be better understood by reading the following detailed description of presently preferred embodiments of the invention, when considered in connection with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a diagram illustrating an example of a position specifying process according to an embodiment;

FIG. **2** is a diagram illustrating an example of the configuration of a position specifying system according to the embodiment;

FIG. **3** is a diagram illustrating an example of a base station storage unit according to the embodiment;

FIG. **4** is a diagram illustrating an example of a floor storage unit according to the embodiment;

FIG. **5** is a diagram illustrating an example of a GMM storage unit according to the embodiment;

FIG. **6** is a diagram illustrating an example of a GMM according to the embodiment;

FIG. **7** is a diagram illustrating an example of an initial arrangement of particles in a position estimation process according to the embodiment;

FIG. **8** is a diagram illustrating an example of the particles after rearrangement in the position estimation process according to the embodiment;

FIG. **9** is a diagram illustrating an example of an estimated-value calculation process according to the embodiment;

FIG. **10** is a diagram illustrating an example of an estimated-value calculation process according to the embodiment;

FIG. **11** is a flowchart illustrating the position specifying process performed by the position specifying server according to the embodiment;

FIG. **12** is a flowchart illustrating a determination process performed by the position specifying server according to the embodiment;

FIG. **13** is a flowchart illustrating the position estimation process performed by the position specifying server according to the embodiment;

FIG. **14** is a flowchart illustrating a calculation process performed by the position specifying server according to the embodiment; and

FIG. **15** is a diagram illustrating a hardware configuration of an example of a computer realizing the function of the position specifying server.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Hereinafter, modes (hereinafter, referred to as "embodiments") for carrying out a position specifying server, a position specifying method, and a recording medium recording a position specifying program according to the present disclosure will be described in detail with reference to the drawings. The position specifying server, the position specifying method, and the recording medium recording the position specifying program according to the embodiments of the present disclosure are not limited. Same reference numerals are given to the same constituent elements of the embodiments to be described below and the description thereof will not be repeated.

1. Overview of Position Specifying Process

Firstly, an example of a position specifying process according to an embodiment will be described with reference to FIG. **1**. FIG. **1** is a diagram illustrating an example of the position specifying process according to the embodiment. In the example of FIG. **1**, a terminal device **10** receives radio waves of base stations **15**A to **15**C and transmits basic service set identifiers (BSSIDs), which are unique IDs of the base stations **15**A to **15**C, and radio wave strengths (also referred to as received signal strength indicators (RSSIs)) to a position specifying server **100**. The position specifying server **100** performs a position specifying process based on the received BSSIDs and the radio wave strengths. When it is not necessary to distinguish the base stations **15**A to **15**C, the base stations **15**A to **15**C are referred to as the base stations **15**.

The terminal device **10** first receives the radio waves of the base stations **15**A to **15**C inside a building **5**. The terminal device **10** detects the BSSIDs of the base stations **15**A to **15**C from the received radio waves and acquires a measured value of the radio wave strength of the received radio wave for each BSSID. The terminal device **10** matches the BSSIDs with the measured values of the radio wave strengths and transmits the BSSIDs and the measured values to the position specifying server **100** via a network N (step S**1** indicated by an arrow in FIG. **1**).

The position specifying server **100** estimates the position of the terminal device **10** for each floor of the building **5** based on the received BSSIDs, the received measured values of the radio wave strengths, and a Gaussian Mixture Model (GMM) stored in a GMM storage unit **123** (step S**2**). Here, the GMM expresses a radio wave strength of a base station in each floor as superposition of a plurality of Gaussian distribution functions. For example, with regard to a floor F3, a GMM **123**A of the base station **15**A, a GMM **123**B of the base station **15**B, and a GMM **123**G of the base station **15**C are stored in the GMM storage unit **123**. For example, with regard to a floor F2, a GMM **124**A of the base station **15**A, a GMM **124**B of the base station **15**B, and a GMM **1240** of the base station **15**C are stored in the GMM storage unit **123**.

For example, the position specifying server **100** is assumed to estimate the position of the terminal device **10** on the floor F3 and the floor F2. The position specifying server **100** estimates the position of the terminal device **10** by performing comprehensive evaluation on the position of the terminal device **10** located on the floor F3 using a particle filter based on the measured values of the radio wave strengths, the GMM **123**A, the GMM **123**B, and the GMM **123**C. The particle filter is one of the time-series filtering methods and is a method of assuming multiple subsequent states as particles and performing tracking while predicting a weighted average as a subsequent state based on likelihood of all particles.

The position specifying server **100** estimates the position of the terminal device **10** located on the floor F3 using the particle filter. The position specifying server **100** calculates estimated values of the radio wave strengths of the base stations **15**A to **15**C at an estimated position **21** of the terminal device **10**. The estimated value of the radio wave strength of the base station **15**A can be calculated as an estimated value **21**A from the GMM **123**A. Likewise, the estimated value of the radio wave strength of the base station **15**B can be calculated as an estimated value **21**B from the GMM **123**B and the estimated value of the radio wave strength of the base station **15**C can be calculated as an estimated value **21**C from the GMM **123**C.

The position specifying server **100** calculates an existence probability of the terminal device **10** on the floor F3 based on the calculated estimated values **21**A to **21**C of the radio wave strengths of the base stations **15**A to **15**C and the measured values of the radio wave strengths of the base stations **15**A to **15**C. For example, the existence probability of the terminal device **10** on the floor F3 can be calculated according to a difference between the estimated values and the measured values of the radio wave strengths. With the other floors such as the floor F2, the position specifying server **100** also calculates an existence probability of the terminal device **10** on each floor such as the floor F2. Here, for example, the existence probabilities of the terminal device **10** on the floors are assumed to be 50% for the floor F3 and 10% for the floor F2.

The position specifying server **100** compares the existence probabilities of the terminal device **10** on the floors with each other. When the terminal device **10** is present at the floor with the highest probability, that is, the floor F3, the position specifying server **100** performs specifying. That is, the position specifying server **100** specifies the estimated position **21** and the floor F3 of the terminal device **10**.

The position specifying server **100** transmits the specified estimated position and the specified floor of the terminal device **10** as positional information to the terminal device **10** (step S**3**). When the terminal device **10** receives the positional information, the terminal device **10** informs a user of the terminal device **10** of the current floor and position, for example, by displaying the position and floor on a map of the building **5** displayed on a screen.

Thus, in the position specifying process according to the embodiment, the position specifying server **100** estimates the position of the terminal device **10** for each floor of the building **5** based on the measured values of the radio wave strengths of the base stations **15**R to **15**C and the GMMs. When the position specifying server **100** estimates the position of the terminal device **10** for each floor, the position specifying server **100** calculates the existence probability of the terminal device **10** on the floor by comparing the measured values of the radio wave strengths at the reception position with the estimated values of the radio wave strengths calculated based on the GMMs and specifies the floor on which the terminal device **10** is present. Therefore, the user of the terminal device **10** can be informed of the current floor and position. Hereinafter, the terminal device **10**, the base stations **15**, the position specifying server **100** performing such a position specifying process will be described in detail.

2. Position Specifying System

Next, a position specifying system **1** according to the embodiment will be described with reference to FIG. **2**. FIG. **2** is a diagram illustrating an example of the configuration of the position specifying system according to the embodiment. As illustrated in FIG. **2**, the position specifying system **1** includes the terminal device **10**, the base stations **15**, and the position specifying server **100**. The terminal device **10** and the position specifying server **100** are connected via the base stations **15** and the network N so as to perform wired or wireless communication. Although not illustrated, the terminal device **10** and the position specifying server **100** may be connected via an another base station (for example, an antenna base station of a cellular phone) independent from the base stations **15** and the network N. In FIG. **2**, the example in which the position specifying system **1** includes one terminal device **10** and three base stations **15** has been described. However, the position specifying system **1** may include more terminal devices **10** and more base stations **15**.

3. Configuration of Terminal Device

Next, the configuration of the terminal device **10** will be described. The terminal device **10** is an information processing device used by a user. The terminal device **10** corresponds to, for example, a cellular phone (for example, a smart phone)

or a personal digital assistant (PDA). As illustrated in FIG. **2**, the terminal device **10** includes a communication unit **11**, a control unit **12**, and a display unit **13**.

Communication Unit **11**

The communication unit **11** is connected to the base stations **15** to transmit and receive information to and from the position specifying server **100** via the network N. The communication unit **11** is connected to the base stations **15** according to a wireless method. The communication unit **11** can use a wireless LAN or the like as the wireless method. The communication unit **11** detects the BSSID from the receivable radio waves from each base station **15** and acquires the measured value of the radio wave strength of the received radio waves for each BSSID.

Control Unit **12**

For example, the control unit **12** is realized by, for example, a central processing unit (CPU) or a micro-processing unit (MPU) by executing a program stored in an internal storage device on a RAM serving as a working area. Further, for example, the control unit **12** is realized by an integrated circuit such as an application specific integrated circuit (ASIC) or a field programmable gate array (FPGA).

The control unit **12** matches the BSSIDs of the base stations **15** acquired by the communication unit **11** with the measured values of the radio wave strengths and transmits the BSSIDs and the measured values to the position specifying server **100** via the communication unit **11** and the network N. For example, the control unit **12** maps the positional information received from the position specifying server **100** on the map and displays the positional information on the display unit **13**. The control unit **12** performs various kinds of information processing by controlling the entire terminal device **10**.

Display Unit **13**

The display unit **13** is a display device that displays various kinds of information. For example, the display unit **13** is realized by a liquid crystal display or the like. When a touch panel is utilized as an input unit (not illustrated), the display unit **13** and the input unit are integrated.

4. Configuration of Base Station

Next, the configuration of the base station **15** will be described. The base station **15** is, for example, a wireless base station of a wireless LAN, is connected to the terminal device **10** according to a wireless method, and is connected to the position specifying server **100** via the network N. The base station **15** conforms to, for example, IEEE 802.11a/b/g/n standards.

5. Configuration of Position Specifying Server

Next, the configuration of the position specifying server **100** will be described. The position specifying server **100** is a server device that estimates the position of the terminal device **10** for each floor based on the BSSID and the radio wave strength received from the terminal device **10** and the GMM stored in the GMM storage unit **123** to be described below. As illustrated in FIG. **2**, the position specifying server **100** includes a communication unit **110**, a storage unit **120**, and a control unit **130**. The position specifying server **100** may include an input unit (for example, a keyboard or a mouse) that receives various operations from a manager or the like of the position specifying server **100** or a display unit (for example, a liquid crystal display) that displays various kinds of information.

Communication Unit **110**

The communication unit **110** is realized by, for example, a network interface card (NIC). The communication unit **110** transmits and receives information to and from the terminal device **10** via the network N and the base stations **15**.

Storage Unit **120**

The storage unit **120** is realized by, for example, a semiconductor memory device such as a RAM or a flash memory or a storage device such as a hard disk or an optical disc. The storage unit **120** includes a base station storage unit **121**, a floor storage unit **122**, and the GMM storage unit **123**, The storage unit **120** stores an operating system (OS), various programs executed by the control unit **130** and various kinds of data.

Base Station Storage Unit **121**

The base station storage unit **121** stores the BSSIDs or the like of the base stations **15** received by the terminal device **10**. FIG. **3** is a diagram illustrating an example of the base station storage unit according to the embodiment. As illustrated in FIG. **3**, the base station storage unit **121** has items such as "BSSID," "representative latitude," "representative longitude," "MaxRSSI," "GMMFlag," and "receivable floor ID."

The "BSSID" is the BSSID detected from the received radio wave of the base station **15** and is used to identify the base station **15**. The "representative latitude" and the "representative longitude" indicate the latitude and the longitude of a position at which the radio wave strength is the strongest, although the radio wave strengths are measured in advance at a plurality of locations to derive a GMM parameter (the details will be described below). The "MaxRSSI" indicates the maximum measured value among the measured values of the radio wave strengths of the BSSID at the representative latitude and the representative longitude. An example of the first row in FIG. **3**, for example, indicates that −75.0 dBm is measured as the radio wave strength. The "GMMFlag" indicates whether the GMM parameter used for position estimation is already derived. For example, " " indicates that the GMM parameter is derived and "0" indicates that the GMM parameter is not derived. The "receivable floor ID" indicates the floor ID of a floor on which the radio wave of the base station **15** having the BSSID can be received.

Floor Storage Unit **122**

The floor storage unit **122** stores information or the like regarding the floors in the building in which positioning is performed. FIG. **4** is a diagram illustrating an example of the floor storage unit according to the embodiment. As illustrated in FIG. **4**, the floor storage unit **122** has items such as "floor ID," "file name of floor drawing," "width of floor drawing," "height of floor drawing," "latitude and longitude of floor," and "floor number."

The "floor ID" is used to identify a floor. As the floor IDs, unique ID may be allocated so as to correspond to a plurality of buildings, for example. The "file name of the floor drawing" indicates a file of a floor drawing. The floor drawing is, for example, a drawing in which pillars, walls, and the like are drawn. The "width of floor drawing" and the "height of floor drawing" are the number of pixels of the floor drawing in the horizontal and vertical directions. The "latitude and longitude of the floor" is used to confirm an area of the floor and indicates, for example, the latitudes and longitudes of an upper left, a lower left, and an upper right of the floor. The "floor number" indicates which floor the floor is in the building. Based on such information, the pixel coordinates of the floor drawing and the latitude and longitude of the floor can be mutually converted.

GMM Storage Unit **123**

The GMM storage unit **123** stores, for example, the BSSID and the corresponding GMM of each floor. FIG. **5** is a diagram illustrating an example of the GMM storage unit according to the embodiment. As illustrated in FIG. **5**, the

GMM storage unit **123** has items such as "floor ID," "number of BSSIDs," "BSSID, "K," "π," "μ_x," "μ_y," "Σ_{11}," "Σ_{12}," and "Σ_{22}."

The "floor ID" is used to identify a floor. The "number of BSSIDs" indicates the number of base stations **15** receivable on the floor, that is, the number of BSSIDs. The "BSSID" is used to identify the base station **15**. The "K" is a GMM parameter and indicates a mixture number of normal distributions. The "π" is a GMM parameter and indicates a mixture coefficient indicating a weight of each normal distribution. A sum of all of the mixture coefficients π is 1. The "μ_x" and "μ_y" are GMM parameters and indicate averages of the normal distributions in the x and y directions. The "Σ_{11}," "Σ_{12}," and "Σ_{22}" are GMM parameters and indicate a variance covariance matrix of the normal distributions. Here, a GMM used to calculate the GMM parameters is expressed in Equation (1). Equation (1) is an equation that is expressed by superimposing the normal distributions even in consideration of normalization and the GMM parameters are derived based on this equation. Equation (2) expresses a conversion expression between the radio wave strength RSSI and the GMM. Coefficients α and β can be calculated according to the method of least squares (not illustrated).

$$p(x,y)\cong\Sigma_k{}^n\pi_k N(x,y|\mu_k,\sigma_k) \quad (1)$$

$$\mathrm{RSSI}(x,y)=\alpha\cdot p(x,y)+\beta \quad (2)$$

The shape of a two-dimensional GMM is determined by an average μ, a variance covariance matrix Σ, and a mixture coefficient π of an individual normal distribution. In the position specifying server **100**, a distribution of the radio wave strengths of a floor is shown using the GMM.

Here, calculation of the GMM will be described. The calculation of the GMM is based on a paper "A Wireless LAN Location Estimation Method Based on Gaussian Mixture Model" (SUSUMU FUJITA, KATSUHIKO KAJI, and NOBUO KAWAGUCHI: Journal of Information Processing Society of Japan, Vol. 52 No. 3 1069 to 1081 (March 2011)).

First, an administrator of the position specifying server **100** measures the radio wave strengths of the base stations **15** on a given floor using the terminal device **10** or another measurement device. The measurement points of the radio wave strengths are set, for example, in interval of a few meters or the like. The administrator performs the measurement a plurality of times at each measurement point and sets the average of the measurements as the radio wave strengths at the measurement point. The administrator performs conversion into a two-dimensional point distribution based on data regarding the radio wave strengths at the plurality of measurement points. The conversion into the two-dimensional point distribution is performed by dividing a region at each measurement point and distributing the number of points according to the radio wave strength to each region. In the division of the region, Voronoi division can be used.

Subsequently, the point distribution is converted into a GMM using an EM algorithm. In the EM algorithm, there are two update procedures, an E step and an M step. The E step and the M step are repeated until a convergence criterion is satisfied by calculating a log likelihood function. An example of the GMM calculated in this way is illustrated in FIG. **6**. FIG. **6** is a diagram illustrating an example of the GMM according to the embodiment. The GMM is a combination of Gaussian functions (bell type functions) and can be expressed as a so-called heat map with a shape of mountains. In FIG. **6**, contours of the heat map, that is, the values of the same radio wave strengths or portions within predetermined ranges are illustrated by the same hatching.

Control Unit **130**

Referring back to FIG. **2**, the control unit **130** is realized, for example, by a CPU or an MPU by executing a program stored in an internal storage device on a RAM serving as a working area. Further, the control unit **130** is realized by, for example, an integrated circuit such as an ASIC or an FPGA.

As illustrated in FIG. **2**, the control unit **130** includes a determination unit **131**, an estimation unit **132**, a calculation unit **133**, and a specifying unit **134**. The control unit **130** realizes or performs an information processing function or operation to be described below. An internal configuration of the control unit **130** is not limited to the configuration illustrated in FIG. **2**, but another configuration may be realized as long as the configuration is a configuration for performing information processing to be described below.

Determination Unit **131**

When the determination unit **131** receives the BSSIDs and the measured values of the radio wave strengths from the terminal device **10**, the determination unit **131** counts the number of the unique BSSIDs for each floor ID, that is, each floor of the building. That is, the determination unit **131** extracts the number of BSSIDs of the base stations **15** receivable only on a given floor among the received BSSIDs with reference to the base station storage unit **121**. When there is no unique BSSID, the determination unit **131** extracts a receivable floor as a feasible floor with reference to the base station storage unit **121** and outputs the floor ID and the measured value of the radio wave strength of the extracted floor to the estimation unit **132**.

When there are the unique BSSIDs, the determination unit **131** determines the floor on which the number of unique BSSIDs is the maximum. When there is only one floor on which the number of unique BSSIDs is the maximum, the determination unit **131** specifies the determined floor as the floor on which the terminal device **10** is present. When there is a plurality of floors in which the number of unique BSSIDs is the maximum, the determination unit **131** specifies the floor to which the BSSID matched with the maximum measured value of the radio wave strength belongs among the unique BSSIDs, as the floor on which the terminal device **10** is present.

The determination unit **131** extracts the BSSID for which the measured value of the radio wave strength is larger than a predetermined threshold value. When the BSSID for which the measured value of the radio wave strength is larger than the predetermined threshold value is extractable, the determination unit **131** outputs the extracted BSSID to the estimation unit **132**. When the BSSID for which the measured value of the radio wave strength is larger than the predetermined threshold value is not extractable, for example, the determination unit **131** lowers the predetermined threshold value by 10 dBm and extracts the BSSID again. When the BSSID for which the measured value of the radio wave strength is larger than the lowered threshold value is extractable, the determination unit **131** outputs the extracted BSSID to the estimation unit **132**. When the BSSID for which the measured value of the radio wave strength is larger than the lowered threshold value is not extractable, for example, the determination unit **131** lowers the predetermined threshold value by 10 dBm and extracts the BSSID further again. When the BSSID for which the measured value of the radio wave strength is larger than the threshold value lowered twice is extractable, the determination unit **131** outputs the extracted BSSID, the floor ID of the specified floor, and the measured value of the radio wave strength to the estimation unit **132**. When the BSSID for which the measured value of the radio wave strength is larger than the threshold value lowered twice is not extractable, the

determination unit **131** performs an error process. Further, the determination unit **131** outputs the measured value of the radio wave strength to the calculation unit **133**.

Estimation Unit **132**

The estimation unit **132** receives the floor IDs, the BSSIDs, and the measured values of the radio wave strengths of the feasible floors or the specified floors from the determination unit **131**. When the floor IDs of the feasible floors are input, for example, the estimation unit **132** selects one floor ID in an ascending order of the floor IDs. With regard to the floor of the input floor ID, the estimation unit **132** determines whether the BSSID for which the measured value of the radio wave strength is larger than the threshold value is extracted. When the BSSID for which the measured value of the radio wave strength is larger than the threshold value is not extracted, that is, the floor ID of the feasible floor is input, the estimation unit **132** extracts the BSSID for which the measured value of the radio wave strength is larger than the predetermined threshold value. When the BSSID for which the measured value of the radio wave strength is larger than the threshold value is extracted and the BSSID for which the measured value of the radio wave strength is larger than the predetermined threshold value is extractable, the estimation unit **132** reads the GMM parameters of the extracted BSSID on the floor from the GMM storage unit **123** and sets the GMM parameters in the particle filter.

When the BSSID for which the measured value of the radio wave strength is larger than the predetermined threshold value is not extractable or the GMM parameters cannot be set in the particle filter, for example, the estimation unit **132** lowers the predetermined threshold value by 10 dBm and extracts the BSSID again. The estimation unit **132** attempts to extract the BSSID by lowering the threshold values twice, as in the determination unit **131**. When the threshold value is lowered twice and the BSSID is not extractable, the estimation unit **132** performs an error process. When the GMM parameters can be set in the particle filter, the estimation unit **132** estimates the position of the terminal device **10** using the particle filter. When the floor ID of the feasible floor is input from the determination unit **131**, the estimation unit **132** outputs the estimated position of the terminal device **10** and the floor ID used in the estimation to the calculation unit **133**. When the floor ID of the specified floor is input from the determination unit **131**, the estimation unit **132** transmits information regarding the estimated position of the terminal device **10**, the floor ID of the specified floor, the drawing of the specified floor read from the floor storage unit **122**, and the like as positional information to the terminal device **10** via the communication unit **110**.

Here, estimation of the position using the particle filter will be described. FIG. **7** is a diagram illustrating an example of an initial arrangement of particles in a position estimation process according to the embodiment. In the example of FIG. **7**, particles **26** are arranged evenly on the floor F2. Each particle **26** moves according to an existence probability in the GMM of the base stations **15**. That is, each particle **26** performs weighting according to the existence probability and performs re-sampling in addition to random walk. When a weight of each particle **26** is treated as a probability of a place to which other particles **26** moves subsequently, most of the other particles **26** in the periphery of the particle **26** with a large weight are rearranged. FIG. **8** is a diagram illustrating an example after the rearrangement of the particles in the position estimation process according to the embodiment. In the example of FIG. **8**, for example, the other particles **26** gather together in the periphery of the particle **26** with the large weight. That is, an estimated position **27** of the terminal device **10** can be estimated to be near the particle **26** with the large weight.

Calculation Unit **133**

The calculation unit **133** receives the estimated position of the terminal device **10** and the floor ID from the estimation unit **132**. The calculation unit **133** also receives the measured value of the radio wave strengths from the determination unit **131**. The calculation unit **133** extracts the BSSID (base station **15**) receivable on the floor indicated by the floor ID based on the floor ID with reference to the base station storage unit **121**. The calculation unit **133** reads the GMM of the extracted BSSID from the GMM storage unit **123**, calculates the radio wave strength of the BSSID at the estimated position of the terminal device **10**, and sets the calculated value as an estimated value of the radio wave strength.

Here, the calculation of the estimated value of the radio wave strength of the BSSID at the estimated position of the terminal device **10** will be described. FIG. **9** is a diagram illustrating an example of an estimated-value calculation process according to the embodiment. For example, the estimated position of the terminal device **10** is assumed to be the estimated position **21**, the floor ID is assumed to be F3, the base stations **15** receivable on the floor F3 are assumed to be the base stations **15**A to **15**C, and the GMMs corresponding to the base stations **15**A to **15**C are assumed to be the GMMs **123**A to **123**C. At this time, the calculation unit **133** calculates the estimated value **21**A of the radio wave strength from the GMM **123**A at the estimated position **21**. Likewise, the calculation unit **133** calculates the estimated value **21**B of the radio wave strength from the GMM **123**E at the estimated position **21** and calculates the estimated value **21**C of the radio wave strength from the GMM **123**C at the estimated position **21**.

The calculation unit **133** calculates the existence probabilities of the terminal device **10** on the floor based on the normal distributions from the received measured values of the radio wave strengths and the estimated values of the radio wave strengths of the respective BSSIDs at the estimated position **21**. The existence probability of the terminal device **10** on the floor can be calculated, for example, according to a difference between the estimated value and the measured value of the radio wave strength. Here, in the example of FIG. **9**, the measured values of the radio wave strengths are assumed to be measured values **20**A to **20**C. At this time, the measured values **20**A to **20**C are assumed to correspond to a portion with a circular shape on the GMM, as illustrated in a horizontal plane of FIG. **9**. Here, there are portions in which the estimated values **21**A to **21**C of the radio wave strengths and the measured values **20**A to **20**C of the radio wave strengths overlap each other. That is, it can be said that there are rarely differences between the estimated values **21**A to **21**C of the radio wave strengths and the measured values **20**A to **20**C of the radio wave strengths. Here, the probability can be expressed as a one-dimensional normal distribution expressed in Equation (3) for each BSSID. For example, the existence probability of the terminal device **10** on the floor can be set to an average value of the probabilities of the BSSIDs, as expressed in Equation (4), in the case of a floor A in which three BSSIDs are extractable. For example, in the case of a floor B in which two BSSIDs are extractable, the probability can be set to an average value of the probabilities of the BSSIDs, as expressed in Equation (5).

$$f(RSSI, E) = \frac{1}{\sqrt{2\pi}} e^{-\frac{(RSSI-E)^2}{2}} \quad (3)$$

$$P_A = \frac{f(RSSI_{A1}, E_{A1}) + f(RSSI_{A2}, E_{A2}) + f(RSSI_{A3}, E_{A3})}{3} \quad (4)$$

$$P_B = \frac{f(RSSI_{B1}, E_{B1}) + f(RSSI_{B2}, E_{B2})}{2} \quad (5)$$

Here, as another example, the floor F2 is illustrated in FIG. **10**. FIG. **10** is a diagram illustrating an example of an estimated-value calculation process according to the embodiment. In the example of FIG. **10**, an estimated position of the terminal device **10** is assumed to be an estimated position **25** and measured values of the radio wave strengths are indicated by marks Δ and are assumed to be measured values **24**A to **24**C. The GMMs corresponding to the base stations **15**A to **15**C are assumed to be the GMMs **124**A to **124**C. At this time, since there is no corresponding value on the GMM **124**A, the measured value **24**A is the nearest value, that is, a value of a summit point of a mountain of the GMM **124**A, as illustrated on a horizontal plane of FIG. **10**. A position corresponding to the measured value **24**B has a circular shape, as illustrated on the horizontal plane of FIG. **10** on the GMM. Further, with regard to the measured value **24**C, a corresponding value on the GMM **124**C is assumed to be exactly a summit point of the mountain.

The calculation unit **133** calculates an estimated value **25**A of the radio wave strength from the GMM **124**A at the estimated position **25**. Likewise, the calculation unit **133** calculates an estimated value **25**B of the radio wave strength from the GMM **124**B at the estimated position **25** and calculates an estimated value **25**C of the radio wave strength from the GMM **124**C at the estimated position **25**. At the estimated position **25**, however, the radio wave strength is equal to or less than an estimation limit with regard to the GMM **1240**. Therefore, for example, the calculation unit **133** sets −120 dBm as the estimated value **25**C.

In the example of FIG. **10**, when differences between the estimated values **25**A to **25**C of the radio wave strengths and the measured values **24**A to **24**C of the radio wave strengths are evaluated, the measured value **24**A is larger between the estimated value **25**A and the measured value **24**A. Further, the estimated value **252** and the measured value **24**B are close values, but the measured value **24**B is larger. Furthermore, the measured value **24**C is larger between the estimated value **25**C and the measured value **24**C. That is, when the existence probability of the terminal device **10** on the floor is calculated from the estimated values **25**A to **25**C of the radio wave strengths and the measured values **24**A to **24**C of the radio wave strengths using Equation (3) to Equation (5), the probability is smaller than in the example of FIG. **9**.

The calculation unit **133** determines whether the position of the terminal device **10** is estimated for all of the floor IDs of the feasible floors. When the feasible floor remains, the calculation unit **133** instructs the estimation unit **132** to perform the position estimation process and the calculation process on the subsequent floor ID. When the position of the terminal device **10** is estimated for all of the feasible floors, the calculation unit **133** matches the floor ID of each floor with the calculated estimated position and the calculated existence probability of the terminal device **10** on each floor and outputs the floor ID, the estimated position, and the existence probability to the specifying unit **134**.

Specifying Unit **134**

When the estimated position and the existence probability of the terminal device **10** on each floor are input from the calculation unit **133**, the specifying unit **134** compares the existence probabilities of the terminal device **10** on the floors with each other. The specifying unit **134** specifies the floor with the highest existence probability of the terminal device **10** among the compared floors as the floor on which the terminal device **10** is present. The specifying unit **134** transmits information regarding the estimated position of the terminal device **10**, the floor ID of the specified floor, the drawing of the specified floor read from the floor storage unit **122**, and the like as positional information to the terminal device **10** via the communication unit **110**.

6. Position Specifying Process

Next, a position specifying process performed by the position specifying system **1** according to the embodiment will be described. FIG. **11** is a flowchart illustrating the position specifying process performed by the position specifying server according to the embodiment.

First, the terminal device **10** receives radio waves of the base stations **15**A to **150** within the building **5**. The terminal device **10** detects the BSSIDs of the base stations **15**A to **150** from the received radio waves and acquires measured values of the radio wave strengths of the radio waves received for each BSSID. The terminal device **10** matches the BSSIDs with the measured values of the radio wave strengths and transmits the BSSIDs and the measured values to the position specifying server **100** via the network N.

The determination unit **131** of the position specifying server **100** receives the BSSIDs and the measured values of the radio wave strengths from the terminal device **10** (step S**11**). The determination unit **131** extracts and counts the number of BSSIDs (unique BSSIDs) of base stations **15** receivable on only a given floor among the received BSSIDs with reference to the base station storage unit **121** (step S**12**). The determination unit **131** determines whether there are the unique BSSIDs (step S**13**). When there is no unique BSSID (No in step S**13**), the determination unit **131** extracts the receivable floor as feasible floor from the received BSSIDs with reference to the base station storage unit **121** and outputs the floor ID of the extracted floor and the measured value of the radio wave strength to the estimation unit **132** (step S**16**). When there are the unique BSSIDs (Yes in step S**13**), the determination unit **131** performs a determination process (step S**14**).

Here, the determination process will be described with reference to FIG. **12**. FIG. **12** is a flowchart illustrating the determination process performed by the position specifying server according to the embodiment. The determination unit **131** determines the floors in which the number of unique BSSIDs is the maximum (step S**141**). The determination unit **131** determines whether the number of floors in which the number of unique BSSIDs is the maximum is one (step S**142**). When the number of floors in which the number of unique BSSIDs is the maximum is one (Yes in step S**142**), the determination unit **131** specifies the determined floor as the floor on which the terminal device **10** is present (step S**143**). When the number of floors in which the number of unique BSSIDs is the maximum is two or more (No in step S**142**), the determination unit **131** specifies the floor to which the BSSID matched with the maximum measured value of the radio wave strength belongs among the unique BSSIDs, as the floor on which the terminal device **10** is present (step S**144**).

The determination unit **131** sets 1 as an initial value of the number of times n that the BSSID in which the radio wave strength is larger than a threshold value is attempted to be

extracted (step S145). The determination unit 131 extracts the BSSID for which the measured value of the radio wave strength is larger than the predetermined threshold value. The determination unit 131 determines whether the BSSID for which the measured value of the radio wave strength is larger than the predetermined threshold value is extractable (step S146). When the BSSID for which the measured value of the radio wave strength is larger than the predetermined threshold value is extractable (Yes in step S146), the determination unit 131 outputs the extracted BSSID to the estimation unit 132 and performs the position estimation process (step S151).

When the BSSID for which the measured value of the radio wave strength is larger than the predetermined threshold value is not extractable (No in step S146), the determination unit 131 determines whether the number of times n is larger than 2 (step S147). When the number of times n is equal to or less than 2 (No in step S147), the determination unit 131 lowers the predetermined threshold value by 10 dBm (step S148), adds 1 to the number of times n (step S149), and causes the process to return to step S146 to extract the BSSID again. When the number times n is larger than 2 (Yes in step S147), the determination unit 131 performs the error process and ends the process (step S150).

The determination unit 131 repeats the processes of step S146 to step S149 to attempt to extract the BSSID by lowering the predetermined threshold value twice. At this time, when the BSSID for which the measured value is larger than the lowered threshold value is extractable (Yes in step S146), the determination unit 131 outputs the extracted BSSID to the estimation unit 132 and performs the position estimation process (step S151).

Here, the position estimation process will be described with reference to FIG. 13. FIG. 13 is a flowchart illustrating the position estimation process performed by the position specifying server according to the embodiment. When the floor ID of the feasible floor is input from the determination unit 131, that is, the BSSID for which the measured value of the radio wave strength is larger than the threshold value is not extracted, the estimation unit 132 performs the same process as the determination process. Therefore, the estimation unit 132 sets 1 as the initial value of the number of times n that the BSSID for which the radio wave strength is larger than the threshold value is attempted to be extracted (step S1511). When the floor ID of the feasible floor is input, for example, the estimation unit 132 selects one floor ID in an ascending order of the floor IDs. When the floor ID of the specified floor is input, the estimation unit 132 selects this floor ID. With regard to the floor of the selected floor ID, the estimation unit 132 determines whether the BSSID for which the measured value of the radio wave strength is larger than threshold value is extracted (step S1512).

When the BSSID for which the measured value of the radio wave strength is larger than the threshold value is not extracted (No in step S1512), the estimation unit 132 extracts the BSSID for which the measured value of the radio wave strength is larger than the predetermined threshold value. The estimation unit 132 determines whether the BSSID for which the measured value of the radio wave strength is larger than the predetermined threshold value is extractable (step S1513). When the BSSID for which the measured value of the radio wave strength is larger than the predetermined threshold value is extractable (Yes in step S1513), the estimation unit 132 reads the GMM parameters of the extracted BSSID on the floor from the GMM storage unit 123 and sets the GMM parameters in the particle filter (step S1518).

When the BSSID for which the measured value of the radio wave strength is larger than the predetermined threshold value is not extractable (No in step S1513), the estimation unit 132 determines whether the number of times n is larger than 2 (step S1514). When the number of times n is equal to or less than 2 (No in step S1514), the estimation unit 132 lowers the predetermined threshold value by 10 dBm (step S1515), adds 1 to the number of times n (step S1516), causes the process to return to steps S1512 and S1513, and extracts the BSSID again. When the number of times n is larger than 2 (Yes in step S1514), the estimation unit 132 performs the error process and ends the process (step S1517).

When the BSSID for which the measured value of the radio wave strength is larger than the threshold value is not extracted, the estimation unit 132 repeats the processes of step S1512 to step S1516, lowers the predetermined threshold value twice, and attempts to extract the BSSID. At this time, when the BSSID for which the measured value of the radio wave strength is larger than the lowered threshold value is extractable (Yes in step S1512), the estimation unit 132 reads the GMM parameters of the extracted BSSID on the floor from the GMM storage unit 123 and sets the GMM parameters in the particle filter (step S1518).

The estimation unit 132 determines whether the GMM parameters can be set in the particle filter (step S1519). When the GMM parameters can be set in the particle filter (Yes in step S1519), the estimation unit 132 estimates the position of the terminal device 10 using the particle filter (step S1520). When the GMM parameters cannot be set in the particle filter (No in step S1519), the estimation unit 132 allows the process to proceed to step S1514, lowers the threshold value used to extract the BSSID again, and attempts to extract the BSSID for which the measured value of the radio wave strength is larger than the threshold value.

The estimation unit 132 determines whether to estimate the position of the terminal device 10 using the particle filter (step S1521). When the estimation unit 132 can estimate the position of the terminal device 10 using the particle filter (Yes in step S1521), the estimation unit 132 ends the position estimation process and the process returns to the original process. When the estimation unit 132 cannot estimate the position of the terminal device 10 using the particle filter (No in step S1521), the estimation unit 132 performs the error process and ends the process (step S1517).

After the process of step S151 in FIG. 12 ends, referring back to FIG. 11 for description, the estimation unit 132 transmits the information regarding the estimated position of the terminal device 10, the floor ID of the specified floor, the drawing of the specified floor read from the floor storage unit 122, and the like as the positional information to the terminal device 10 via the communication unit 110 (step S15). The control unit 12 of the terminal device 10 maps the positional information received from the position specifying server 100 on, for example, a map and displays the positional information on the display unit 13.

Subsequently, processes will be described after the floor ID of the receivable floor and the measured value of the radio wave strength are output to the estimation unit 132 in step S16 when there is no unique BSSID in step S13. When the floor ID of the feasible floor is input, for example, the estimation unit 132 selects one floor ID in the ascending order of the floor IDs. The estimation unit 132 performs the position estimation process with regard to the floor with the selected floor ID (step S17). Since the position estimation process of step S17 is the same as the position estimation process of step S151, the description thereof will not be repeated.

When the position estimation process ends with regard to one of the floor IDs of the feasible floors, the estimation unit

132 outputs the estimated position of the terminal device 10 and the floor ID used for the estimation to the calculation unit 133.

When the position of the terminal device 10 estimated by the estimation unit 132 and the floor ID are input, the calculation unit 133 performs the calculation process (step S18). Here, the calculation process will be described with reference to FIG. 14. FIG. 14 is a flowchart illustrating the calculation process performed by the position specifying server according to the embodiment.

The calculation unit 133 extracts the BSSIDs (base stations 15) receivable on the floor indicated by the floor ID based on the floor ID with reference to the base station storage unit 121 (step S181). The calculation unit 133 reads the GMMs of the extracted BSSIDs from the GMM storage unit 123 (step S182), calculates the radio wave strengths of the BSSIDs at the estimated position of the terminal device 10, and sets the calculation results as estimated values of the radio wave strengths (step S183).

The calculation unit 133 calculates the existence probability of the terminal device 10 on the floor based on the normal distributions from the measured values of the radio wave strengths input from the determination unit 131 and the estimated values of the radio wave strengths for the respective BSSIDs at the estimated position of the terminal device 10 (step S184).

Referring back to FIG. 11 for the description, the calculation unit 133 determines whether the position of the terminal device 10 is estimated for all of the floor IDs of the feasible floors (step S19). When the position of the terminal device 10 is not estimated for all of the floor IDs of the feasible floors (No in step S19), the process returns to step S17 and the calculation unit 133 performs the processes of step S17 and step S18 on the subsequent floor ID. When the position of the terminal device 10 is estimated for all of the floor IDs of the feasible floors (Yes in step S19), the calculation unit 133 associates the floor ID of each floor with the estimated position and the calculated existence probability of the terminal device 10 on each floor and outputs the floor ID, the estimated position, and the existence probability to the specifying unit 134.

When the estimated position and the existence probability of the terminal device 10 on each floor are input from the calculation unit 133, the specifying unit 134 compares the existence probabilities of the terminal device 10 on each of the floors. The specifying unit 134 specifies the floor on which the existence probability of the terminal device 10 is the highest among the compared floors as the floor on which the terminal device 10 is present (step S20). The specifying unit 134 transmits the information regarding the estimated position of the terminal device 10, the floor ID of the specified floor, the drawing of the specified floor read from the floor storage unit 122, and the like as positional information to the terminal device 10 via the communication unit 110 (step S15). The control unit 12 of the terminal device 10 maps the positional information received from the position specifying server 100 on, for example, a map and displays the positional information on the display unit 13.

7. Advantages

In this way, the position specifying server 100 stores the GMMs corresponding to the base stations receivable by the terminal device and indicating the radio wave strengths on each floor in the storage unit, receives the measured values of the radio wave strengths of the radio waves which the terminal device 10 receives from the base stations 15, and estimates the position of the terminal device 10 for each floor based on the received measured values of the radio wave strengths and the GMMs. Further, the position specifying server 100 calculates the estimated values of the radio wave strengths at the estimated position of the terminal device 10 on each floor based on the GMMs corresponding to the base stations 15 and specifies the floor on which the terminal device 10 is present based on the calculated estimated values of the radio wave strengths and the measured values of the radio wave strengths. Thus, the position specifying server 100 can specify the floor with high accuracy using a small database.

The position specifying server 100 calculates a difference between the calculated estimated value of the radio wave strength and the measured value of the radio wave strength for each base station 15, calculates an existence probability of the terminal device 10 on each floor for each of the base stations 15 according to the calculated difference in the radio wave strength, and specifies the floor on which the terminal device 10 is present based on the calculated existence probability for each base station 15. Thus, the position specifying server 100 can specify the floor with high accuracy based on the existence probability of the terminal device 10 on each floor.

The position specifying server 100 calculates the difference between the calculated estimated value of the radio wave strength and the measured value of the radio wave strength for each of the base stations 15, calculates an average value of probabilities for each base station 15 for which the difference in the radio wave strength is calculated on each floor as an existence probability of the terminal device 10 on each floor according to the calculated difference in the radio wave strength, and specifies the floor on which the terminal device 10 is present based on the calculated existence probability. Thus, the position specifying server 100 can set the average value of the existence probabilities of the terminal device 10 on each floor for each base station 15 as the existence probability of the terminal device 10 on each floor, and thus can specify the floor with high accuracy.

The position specifying server 100 stores floor-unique base station information in which floor-unique base stations (BSSID) received in advance on one floor are associated with the floor in the storage unit. The determination unit 131 determines the floor on which the number of received floor-unique base stations is the largest as the floor on which the terminal device 10 is present. When the determination unit 131 is not able to specify the floor on which the terminal device 10 is present, the position specifying server 100 specifies the floor on which the terminal device 10 is present. Thus, the position specifying server 100 can specify the floor with high accuracy through a lighter process, when there are the floor-unique base stations.

The position specifying server 100 stores floor-unique base station information in which floor-unique base stations (BSSID) received in advance on one floor are associated with the floor in the storage unit. The determination unit 131 determines the floor to which the floor-unique base station of the maximum radio wave strength of the received floor-unique base station belongs as the floor on which the terminal device 10 is present, when there is a plurality of floors in which the number of received floor-unique base stations is the largest. When the determination unit 131 is not able to specify the floor on which the terminal device 10 is present, the position specifying server 100 specifies the floor on which the terminal device 10 is present. Thus, the position specifying server 100 can specify the floor with high accuracy through a lighter process, even when there are the plurality of floor-unique base stations.

8. Others

The embodiments of the present disclosure have been described above in detail with reference to the drawings. The

embodiments are merely examples and should be apparent to those skilled in the art that the aspects described in the summary of the invention and various modifications and corrections can be realized as other embodiments.

In the above-described embodiments, the calculation unit **133** uses the average value of the probabilities for each base station **15** as the existence probability of the terminal device **10** on each floor, but the invention is not limited thereto. For example, instead of the average value of the probabilities for each base station **15**, the calculation unit **133** may set a value, which is obtained by dividing a sum of the probabilities for the base stations **15** by the number of base stations on the floor on which the number of base stations **15** for which the difference in the radio wave strength is calculated is the largest among the floors, as the existence probability of the terminal device **10** on each floor. That is, the position specifying server **100** calculates the difference between the calculated estimated value of the radio wave strength and the measured value of the radio wave strength for each base station **15**, calculates the value, which is obtained by dividing the sum of probabilities for the base stations **15** for which the difference in the radio wave strength is calculated on each floor by the number of base stations **15** on the floor on which the number of base stations **15** for which the difference in the radio wave strength is calculated is the largest among the floors, as the existence probability of the terminal device **10** on each floor according to the calculated difference in the radio wave strength, and specifies the floor on which the terminal device **10** is present based on the calculated existence probability. Thus, the position specifying server **100** can perform weighting the floor on which the number of base stations **15** for which the difference in the radio wave strength is calculated is the largest and can specify the floor with high accuracy.

In the above-described embodiments, the determination unit **131** specifies the floor to which the BSSID for which the measured value of the radio wave strength is the maximum belongs among the unique BSSIDs, as the floor on which the terminal device **10** is present, but the invention is not limited thereto. For example, when the maximum radio wave strength of the received floor-unique BSSID (base station **15**) exceeds the maximum radio wave strength of the corresponding floor-unique BSSID stored in the base station storage unit **121**, the determination unit **131** can exclude the floor to which the floor-unique BSSID belongs from the specifying candidates. That is, the position specifying server **100** stores floor-unique base station information in which floor-unique base stations received in advance on one floor are associated with the floor and the maximum radio wave strength of each of the floor-unique base stations in the storage unit. The determination unit **131** excludes the floor to which the floor-unique base stations belong from the specifying candidates, when the maximum radio wave strength of the received floor-unique bases station exceeds the maximum radio wave strength of the corresponding floor-unique base station stored in the storage unit and determines the floor on which the number of received floor-unique base stations is the largest as the floor on which the terminal device **10** is present. When the determination unit **131** is not able to specify the floor on which the terminal device **10** is present, the position specifying server **100** specifies the floor on which the terminal device **10** is present. Thus, the position specifying server **100** can exclude the floor to which the base station **15** with the maximum radio wave strength exceeding the radio wave strength measured in advance belongs from the candidates, and thus can specify the floor with high accuracy with a light process.

In the above-described embodiments, the floor on which the terminal device **10** is present is specified based on the estimated value and the measured value of the radio wave strength, but the invention is not limited thereto. For example, the floor may be specified based on a measured value R of the radio wave strength measured by the terminal device **10** and the maximum radio wave strength Rimax in each floor i. First, the administrator of the position specifying system **1** calculates a difference "dji=Rj−Rimax" for each measurement point j of each floor i in advance. Based on the difference dji, the administrator calculates the maximum value of the difference dji as a parameter x1, the number of positive values of the difference dji as a parameter x2 (that is, indicates another floor), the average value of the difference dji as a parameter x3, and the average of positive values of the difference dji as a parameter x4. Further, the administrator acquires the number of BSSIDs measured in each floor i, that is, the number of base stations **15**. Next, coefficients k1 to k5 are specified through discriminant analysis of multivariable analysis using Equation (6). Here, Equation (6) is 1 in a correct case and is 0 in an error case. Next, when the terminal device **10** actually performs positioning and the measured value of the measured radio wave strength measured by the terminal device **10** is assumed to be R, the position specifying server **100** can calculate a difference "di=R−Rimax," calculate the parameters x1 to x5, and specify the floor on which Equation (6) is the maximum as the floor on which the terminal device **10** is present. Thus, the position specifying server **100** can specify the floor on which the terminal device **10** is present based on the maximum radio wave strength of each floor.

$$f(xi)=k1\cdot x1+k2\cdot x2+k3\cdot x3+k4\cdot x4+k5\cdot x5 \quad (6)$$

The above-described position specifying server **100** may be realized by a plurality of server computers or may be realized by a single server computer. Further, an external platform is called by an application programming interface (API), network computing, or the like to be realized depending on the functions. In this way, the configuration can be flexibly changed.

The position specifying server **100** according to the above-described embodiment is realized by, for example, a computer **200** that has a configuration illustrated in FIG. **15**. FIG. **15** is a diagram illustrating an example of a hardware configuration of a computer realizing the functions of the position specifying server. The computer **200** includes a central processing unit (CPU) **201**, a random access memory (RAM) **202**, a read-only memory (ROM) **203**, a hard disk drive (HDD) **204**, a communication interface (I/F) **205**, an input/output interface (I/F) **206**, and a media interface (I/F) **207**.

The CPU **201** operates based on a program stored in the ROM **203** or the HDD **204** and controls each unit. The ROM **203** stores, for example, a boot program performed by the CPU **201** at the time of activation of the computer **200** or a program dependent on hardware of the computer **200**.

The HDD **204** stores, for example, a program executed by the CPU **201** and data used by the program. The communication interface **205** receives data from another device via a communication line **209**, transmits the data to the CPU **201**, and transmits data generated by the CPU **201** to another device via the communication line **209**.

The CPU **201** controls an output device such as a display or a printer or an input device such as a keyboard or a mouse via the input/output interface **206**. The CPU **201** acquires data from the input device via the input/output interface **206**. The CPU **201** outputs generated data to the output device via the input/output interface **206**.

The media interface **207** reads a program or data stored in a recording medium **208** and supplies the program or the data to the CPU **201** via the RAM **202**. The CPU **201** loads the

program on the RAM **202** from the recording medium **208** via the media interface **207** and executes the loaded program. The recording medium **208** is, for example, an optical recording medium such as a digital versatile disc (DVD) or a phase change rewritable disk (PD), a magneto-optical recording medium such as a magneto-optical disk (MO), a tape medium, a magnetic recording medium, or a semiconductor memory.

When the computer **200** functions as the position specifying server **100** according to the embodiment, the CPU **201** of the computer **200** realizes the functions of the determination unit **131**, the estimation unit **132**, the calculation unit **133**, and the specifying unit **134** by executing the program loaded on the RAM **202**. The HDD **204** stores data stored in the base station storage unit **121**, the floor storage unit **122**, and the GMM storage unit **123**.

The CPU **201** of the computer **200** reads the program from the recording medium **208** and executes the program. As another example, the CPU **201** may acquire the programs from another device via the communication line **209**.

The position specifying server according to the present disclosure is capable of specifying a floor with high accuracy even using a small database.

Although the invention has been described with respect to specific embodiments for a complete and clear disclosure, the appended claims are not to be thus limited but are to be construed as embodying all modifications and alternative constructions that may occur to one skilled in the art that fairly fall within the basic teaching herein set forth.

What is claimed is:

1. A position specifying server for use with a terminal device, the position specifying server comprising:

a non-transitory computer readable storage medium programmed to store Gaussian Mixture Models corresponding to base stations of radio waves receivable by the terminal device and indicating radio wave strengths on each floor; and

a processor programmed to:

receive measured values of the radio wave strengths of radio waves which the terminal device receives from the base stations;

calculate a difference between the calculated estimated value of the radio wave strength and the measured value of the radio wave strength for each of the base stations;

estimate a position of the terminal device for each floor based on the by received measured values of the radio wave strengths and the Gaussian Mixture Models by calculating a value representing an existence probability of the terminal device on each floor according to the calculated difference in the radio wave strength, which is obtained by dividing a sum of probabilities for the base station for which the difference in the radio wave strength is calculated on each floor by the number of base stations on the floor on which the number of base stations for which the difference in the radio wave strength is calculated is the largest among the floors;

calculate an estimated value of the radio wave strengths at the estimated position of the terminal device on each floor based on the Gaussian Mixture Models; and

specify the floor on which the terminal device is present based on the calculated estimated values of the radio wave strengths, the measured values of the radio wave strengths and the calculated existence probability.

2. The position specifying server according to claim **1**, wherein the processor calculates a difference between the calculated estimated value of the radio wave strength and the measured value of the radio wave strength for each base station, calculates an existence probability of the terminal device on each floor for each of the base stations according to the calculated difference in the radio wave strength, and specifies the floor on which the terminal device is present based on the calculated existence probability for each base station.

3. The position specifying server according to claim **1**, wherein the processor calculates a difference between the calculated estimated value of the radio wave strength and the measured value of the radio wave strength for each of the base stations, calculates an average value of probabilities for each base station for which the difference in the radio wave strength is calculated on each floor as an existence probability of the terminal device on each floor according to the calculated difference in the radio wave strength, and specifies the floor on which the terminal device is present based on the calculated existence probability.

4. The position specifying server according to claim **1**,

wherein the storage medium stores floor-unique base station information in which floor-unique base stations received in advance on one floor are associated with the floor,

wherein the processor is programmed to:

determine the floor on which the number of received floor-unique base stations is the largest as the floor on which the terminal device is present, and

wherein, when the processor is not able to determine the floor on which the terminal device is present, the processor specifies the floor on which the terminal device is present.

5. The position specifying server according to claim **1**,

wherein the storage medium stores floor-unique base station information in which floor-unique base stations received in advance on one floor are associated with the floor and a maximum radio wave strength of each of the floor-unique base stations,

wherein the processor is programmed to:

exclude the floor to which the floor-unique base stations belong from specifying candidates, when the maximum radio wave strength of the received floor-unique bases station exceeds the maximum radio wave strength of the corresponding floor-unique base station stored in the storage medium, and determines the floor on which the number of received floor-unique base stations is the largest as the floor on which the terminal device is present, and

wherein, when the processor is not able to determine the floor on which the terminal device is present, the processor specifies the floor on which the terminal device is present.

6. The position specifying server according to claim **1**,

wherein the storage medium stores floor-unique base station information in which floor-unique base stations received in advance on one floor are associated with the floor,

wherein the processor is programmed to:

determine the floor to which the floor-unique base station of the maximum radio wave strength of the received floor-unique base station belongs as the floor on which the terminal device is present, when there is a plurality of floors in which the number of received floor-unique base stations is the largest, and

wherein, when the processor is not able to determine the floor on which the terminal device is present, the processor specifies the floor on which the terminal device is present.

7. The position specifying server according to claim **1**, wherein each Gaussian Mixture Model indicates radio wave strengths on one floor, corresponding to base stations that are each placed on one of a plurality of floors.

8. The position specifying server according to claim **1**, wherein the processor is programmed to calculate the estimated values of the radio wave strengths of base stations at the estimated position of the terminal device on each floor based on the Gaussian mixture model corresponding to the base stations.

9. A position specifying method of a position specifying server for use with a terminal device, the position specifying method comprising:

storing Gaussian Mixture Models corresponding to base stations of radio waves receivable by the terminal device and indicating radio wave strengths on each floor in a non-transitory computer readable storage medium;

receiving measured values of the radio wave strengths of radio waves which the terminal device receives from the base stations;

estimating a position of the terminal device for each floor based on the received measured values of the radio wave strengths and the Gaussian Mixture Models; and

calculating an estimated value of the radio wave strengths at the estimated position of the terminal device on each floor based on the Gaussian Mixture Models and specifying the floor on which the terminal device is present based on the calculated estimated values of the radio wave strengths and the measured values of the radio wave strengths, wherein

in the specifying of the floor, (i) a difference between the calculated estimated values of the radio wave strengths and the measured values of the radio wave strength is calculated for each of the base station, (ii) a value is calculated as an existence probability of the terminal device on each floor according to the calculated difference in the radio wave strength, which is obtained by dividing a sum of probabilities for the base stations for which the difference in the radio wave strength is calculated on each floor by the number of base stations on the floor on which the number of base stations for which the difference in the radio wave strength is calculated is the largest among the floors, and (iii) the floor on which the terminal device is present is specified based on the calculated existence probability.

10. The position specifying method according to claim **9**, wherein in the specifying of the floor, a difference between the calculated estimated value of the radio wave strength and the measured value of the radio wave strength is calculated for each of the base stations, an existence probability of the terminal device on each floor is calculated for each base station according to the calculated difference in the radio wave strength, and the floor on which the terminal device is present is specified based on the calculated existence probability for each base station.

11. The position specifying method according to claim **9**, wherein in the specifying of the floor, a difference between the calculated estimated value of the radio wave strength and the measured value of the radio wave strength is calculated for each of the base stations, an average value of probabilities for each base station for which the difference in the radio wave strength is calculated on each floor is calculated as an existence probability of the terminal device on each floor according to the calculated difference in the radio wave strength, and the floor on which the terminal device is present is specified based on the calculated existence probability.

12. The position specifying method according to claim **9**,

wherein the storage medium stores floor-unique base station information in which floor-unique base stations received in advance on one floor are associated with the floor,

wherein the position specifying server further performs:

determining the floor on which the number of received floor-unique base stations is the largest as the floor on which the terminal device is present, and

wherein when the floor on which the terminal device is present is not able to be specified in the determining of the floor, the floor on which the terminal device is present is specified in the specifying of the floor.

13. The position specifying method according to claim **9**,

wherein the storage medium stores floor-unique base station information in which floor-unique base stations received in advance on one floor are associated with the floor and a maximum radio wave strength of each of the floor-unique base stations,

wherein the position specifying server further performs:

excluding the floor to which the floor-unique base stations belong from specifying candidates, when the maximum radio wave strength of the received floor-unique bases station exceeds the maximum radio wave strength of the corresponding floor-unique base station stored in the storage medium; and

determining the floor on which the number of received floor-unique base stations is the largest as the floor on which the terminal device is present, and

wherein when the floor on which the terminal device is present is not able to be specified in the determining of the floor, the floor on which the terminal device is present is specified in the specifying of the floor.

14. A non-transitory computer readable storage medium storing a position specific program causing a computer to perform steps comprising:

storing Gaussian Mixture Models corresponding to base stations of radio waves receivable by a terminal device and indicating radio wave strengths on each floor in the non-transitory computer readable storage medium or another non-transitory computer readable storage medium;

receiving measured values of the radio wave strengths of radio waves which the terminal device receives from the base stations;

estimating a position of the terminal device for each floor based on the received measured values of the radio wave strengths and the Gaussian Mixture Models;

calculating an estimated value of the radio wave strengths at the estimated position of the terminal device on each floor based on the Gaussian Mixture Models; and

specifying the floor on which the terminal device is present based on the calculated estimated values of the radio wave strengths and the measured values of the radio wave strengths, wherein

in the specifying of the floor, (i) a difference between the calculated estimated value of the radio wave strength and the measured value of the radio wave strength is calculated for each of the base stations, (ii) a value is calculated as an existence probability of the terminal device on each floor according to the calculated difference in the radio wave strength, which is obtained by dividing a sum of probabilities for the base stations for which the difference in the radio wave strength is calcu-

lated on each floor by the number of base stations on the floor on which the number of base stations for which the difference in the radio wave strength is calculated is the largest among the floors, and (iii) the floor on which the terminal device is present is specified based on the calculated existence probability.

15. The non-transitory computer readable storage medium storing the position specific program according to claim **14**, wherein in the specifying of the floor, a difference between the calculated estimated value of the radio wave strength and the measured value of the radio wave strength is calculated for each of the base stations, an existence probability of the terminal device on each floor is calculated for each base station according to the calculated difference in the radio wave strength, and the floor on which the terminal device is present is specified based on the calculated existence probability for each base station.

16. The non-transitory computer readable storage medium storing the position specific program according to claim **14**, wherein in the specifying of the floor, a difference between the calculated estimated value of the radio wave strength and the measured value of the radio wave strength is calculated for each of the base stations, an average value of probabilities for each base station for which the difference in the radio wave strength is calculated on each floor is calculated as an existence probability of the terminal device on each floor according to the calculated difference in the radio wave strength, and the floor on which the terminal device is present is specified based on the calculated existence probability.

17. The non-transitory computer readable storage medium storing the position specific program according to claim **14**,

wherein the storage medium or the another storage medium stores floor-unique base station information in which floor-unique base stations received in advance on one floor are associated with the floor,

wherein the computer is caused to further perform:

determining the floor on which the number of received floor-unique base stations is the largest as the floor on which the terminal device is present, and

wherein when the floor on which the terminal device is present is not able to be specified in the determining of the floor, the floor on which the terminal device is present is specified in the specifying of the floor.

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